LARVAL AND JUVENILE GROWTH OF SABLEFISH, *ANOPLOPOMA FIMBRIA*, AS DETERMINED FROM OTOLITH INCREMENTS

The black cod or sablefish, *Anoplopoma fimbria*, has been the subject of an intensifying fishery off the west coast of North America over the last decade. Biological information on this species, however, including data on spawning, early life history, age and growth, and population structure, is relatively meager. Sablefish are widely distributed in the northern Pacific, with adults most abundant at depths of 366-915 m (Hart 1973). Mason et al. (1983) suggested that eggs are spawned and developed in waters deeper than 300 m and colder than 6°C off Canada. Juveniles occur in shallow water, however, and larvae are almost exclusively neustonic (Kendall and Clark[1]). Thus larval development and growth occur in much warmer water than that inhabited by later stages, particularly in the southern portion of the species range.

Sablefish growth has been described by Heyamoto (1962) and Pruter (1954), among others, who used scale annuli to define the growth pattern. More recent work, however, has shown that the age estimates, particularly for older, mature fish, are in error; growth is apparently much slower and longevity much greater than previously thought (Beamish and Chilton 1982). The warmer neustonic habitat of the larvae may result in different growth patterns in early life; ontogenetic changes in growth and habitat are relatively common among deeper living fishes (Boehlert 1982; Luczkovich and Olla 1983). The only observations on growth of young sablefish are those of Heyamoto (1962), who suggested that juveniles of 12-16 cm fork length (FL) were about 6 mo old. In the present study we report on the growth of field-collected larval and juvenile sablefish where age was estimated by enumerating growth increments on the otoliths.

Materials and Methods

Larval and juvenile sablefish were collected in 1981-83. Larvae were taken in 0.5 m neuston nets (Sameoto and Jaroszynski 1969) with 0.505 mm mesh, off the coasts of Oregon and Washington during May 1982 by the RV *Poseydon*. Samples were immediately preserved in 80% ethanol. After sorting,

[1]Kendall, A. W., Jr., and J. Clark. 1982. Ichthyoplankton off Washington, Oregon, and northern California, April-May 1980. Processed Rep. 82-11, 44 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. East, Seattle, WA 98102.

larvae were stored in individual vials labeled with sample number and date. Additional larvae were collected with neuston nets in May 1983 by the RV *Ekvator*. Larger juveniles (> 70 mm standard length (SL)) were taken in a small mesh purse seine deployed from 24 to 40 km off of the Oregon-Washington coasts during the summer months of 1981 (Fig. 1). Specimens were frozen on board and held until measurements and otoliths were taken. Fork lengths to the nearest millimeter were recorded for these larger juveniles and standard lengths to the nearest 0.1 mm were measured for all larvae and small juveniles. No corrections were made for potential shrinkage from preservation of young larvae, but alcohol preservation causes no noticeable shrinkage in length of anchovy larvae (Theilacker 1980). For subsequent analysis, fork lengths were converted to standard length by the relationship SL (mm) = 0.91 FL (mm) − 1.15 (n = 54, r^2 = 0.999), which was based upon specimens 21.7 to 297 mm FL.

Otoliths of larval sablefish were removed and cleaned under a dissecting microscope fitted with polarizing filters. Increments on otoliths from larvae < 26 mm SL were clearly visible from the focus to the margin (Fig. 2); these otoliths were left intact, affixed to microscope slides with histological mounting medium and cover slips, and increments were read in the sagittal plane (see Taubert and Coble 1977 for terminology). For larger larvae and most juveniles, a sagittal section of the otolith provided the clearest increments. The left otolith of every pair was mounted in histological medium on a microscope slide and the

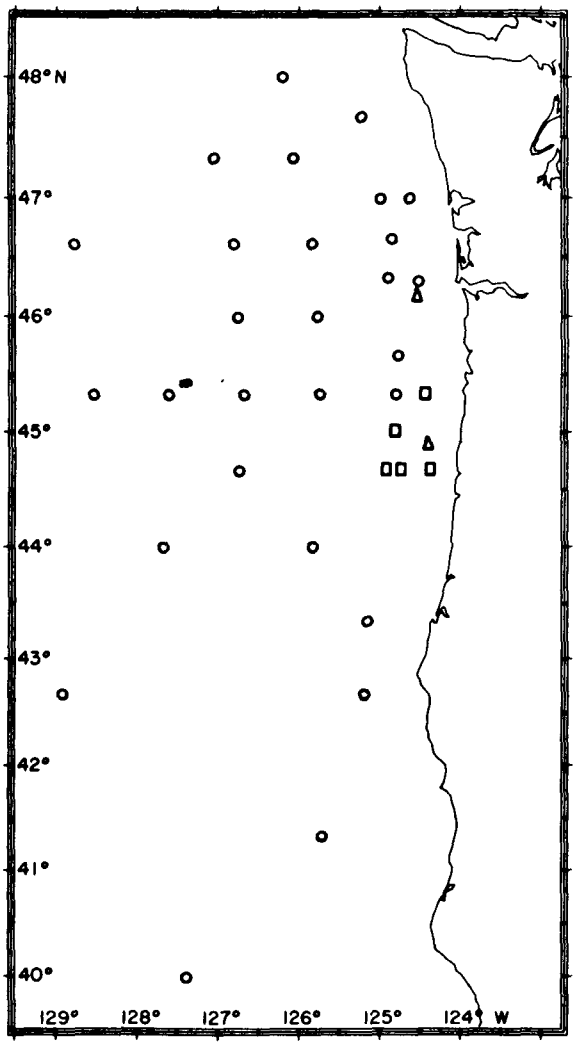

FIGURE 1. – Distribution of *Anoplopoma fimbria* samples, along the Pacific coast, used for age and growth analysis. Circles represent the neuston samples taken during May 1982, triangles represent the purse seine samples taken during summer 1981, and squares represent the 1983 neuston samples.

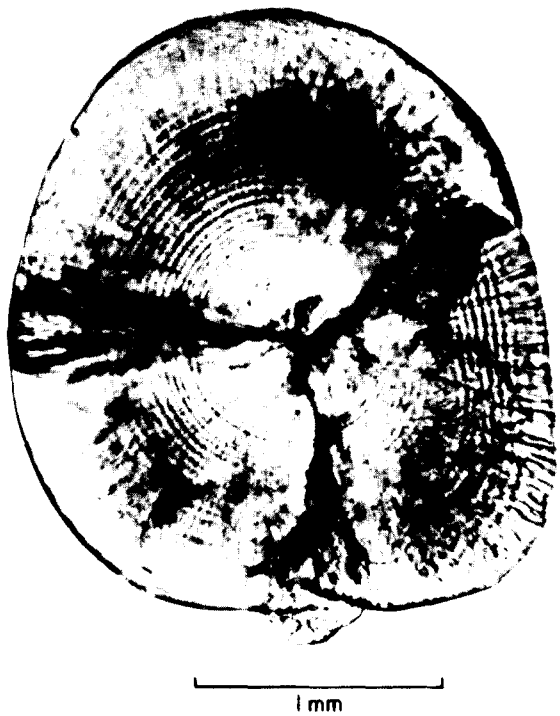

FIGURE 2.—Sagitta otolith from a larval *Anoplopoma fimbria* (22.0 mm SL; duplicate increment counts were 37 and 40 d). Scale bar = 0.1 mm.

internal surface was ground until the focus was visible. The microscope slide was heated and the section was turned over to expose the external surface. Grinding and polishing continued, while care was taken to insure that material was not lost from the margin. The result was a clear, thin section of the otolith in the sagittal plane. For some of the larger juveniles (> 100 mm SL), transverse sections were cut from the otoliths using a diamond saw, mounted on microscope slides, and ground to make the increments clear. All otoliths were read under a compound microscope at 400× or 1,000× magnification. Two independent counts were made for each otolith. These counts were made at least 2 wk apart; the age assigned to each specimen was the mean of the two counts.

Increments, comprised of adjacent light and dark ring pairs, were distinct and clear in the smallest otoliths (Fig. 2), but interpretation became more difficult as the increments became progressively smaller and as changes in growth patterns occurred in the otolith structure of the older specimens. There was no evidence of subdaily patterns in the increments, and each increment was assumed to represent 1 d. Support for the daily deposition of increments was provided by data on three live juvenile sablefish held in the laboratory (Table 1). The specimens were captured by neuston net off Newport, OR, and transported to the laboratory where they were fed to satiation daily on *Artemia*. A check, apparently associated with capture and transfer to the laboratory, was evident on the otolith of each fish. The numbers of increments past this check corresponded closely to days captive; the minor differences are attributed to counting error and/or difficulty in interpretation of the check (Table 1). We thus consider the increments to be deposited with a daily periodicity. Hereafter increment counts will be equated with days after first increment formation; as we discuss later, first increment formation may occur at first feeding.

Data from the 1982-83 larval collections and the 1981 juvenile collections were fitted separately with simple linear regressions. Nonlinear curves (exponential, logistic, and Laird-Gompertz) were fitted to combined data with the NLIN procedure on the SAS[2] statistical package (SAS Institute, Inc. 1982).

TABLE 1.—Growth and increment formation in captive specimens of *Anoplopoma fimbria*. L_1, L_2; standard length (mm) at capture and death, respectively.

Capture date	L_1	L_2	Days captive	Increment past check	Total increments
2 May 1983	19.9	60.4	31	31	63
17 May 1983	14.1	53.4	40	38	95
24 May 1983	53.8	109.7	32	33	87

Results and Discussion

This study considers a total of 105 individuals, including 71 larvae and juveniles (9.8 to 41.2 mm SL) from the 1982 neuston collections, 21 juveniles (102.8 to 259.6 mm SL) from the 1981 purse seine collections, and 13 larvae (10.4 to 25.3 mm SL) taken in the 1983 neuston collections. Mean increment counts ranged from 9 increments for the youngest larva to 180 increments for the oldest juvenile. The abundance of larval sablefish in the neuston (Kendall and Clark footnote 1) at such young ages suggests that larvae move rapidly after hatching from the deep spawning region rather than early growth occurring at depths as suggested by Mason et al. (1983). The difference between the two increment counts for each otolith increased with increasing count, but the coefficient of variation remained the

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

same for the two ranges. For the larvae collected in 1982, with an overall mean of 30.8 increments, the mean difference was 1.67 increments (n = 71, standard deviation (SD) = 1.45). For the 1981 juvenile collections, with overall mean of 109.5 increments, the mean difference between the two estimates was 6.57 increments (n = 21, SD = 5.03).

Growth rates of field-collected larval and juvenile sablefish differ considerably. The data for the 1982 larval collections is described by the line

$$\text{SL} = 0.375\ (\text{age, d}) + 5.27$$
$$n = 71,\ r^2 = 0.838,$$

suggesting a mean growth rate for small larvae of 0.375 mm/d and an intercept of 5.27 mm, which coincides with the size of newly hatched larvae (Mason et al. 1983). Similarly the 1981 juvenile data is described by the line

$$\text{SL} = 1.469\ (\text{age, d}) - 0.926$$
$$n = 21,\ r^2 = 0.822,$$

suggesting a mean growth rate of 1.47 mm/d. Certain of these growth differences may have been a function of gear selection. If net avoidance is a function of fish size, as for most other planktonic organisms (Barkley 1972), then the oldest specimens taken in the neuston gear may have been only the slow-growing members of that cohort. Alternatively, interruptions of increment formation, resulting in underestimates of age, may occur. This has been observed for some species by Geffen (1982). In the laboratory specimens, however, one individual (L_2 = 60.4 mm SL, Table 1) ceased eating for 5-6 d, became emaciated, and died. The last five increments near the margin were smaller than the remainder, but the 1:1 correspondence of days to increments suggests that increment formation continued.

Estimated age-at-length data from all years were combined to describe the growth of sablefish to an age of about 200 d. Comparing exponential, logistic, and Laird-Gompertz growth models, the best fit (as judged by residual sums of squares) was provided by the Laird-Gompertz growth model (Fig. 3) in the form:

$$L_t = L_0\ (A_0/\alpha)\ (1 - \exp\ (-\ \alpha t))$$

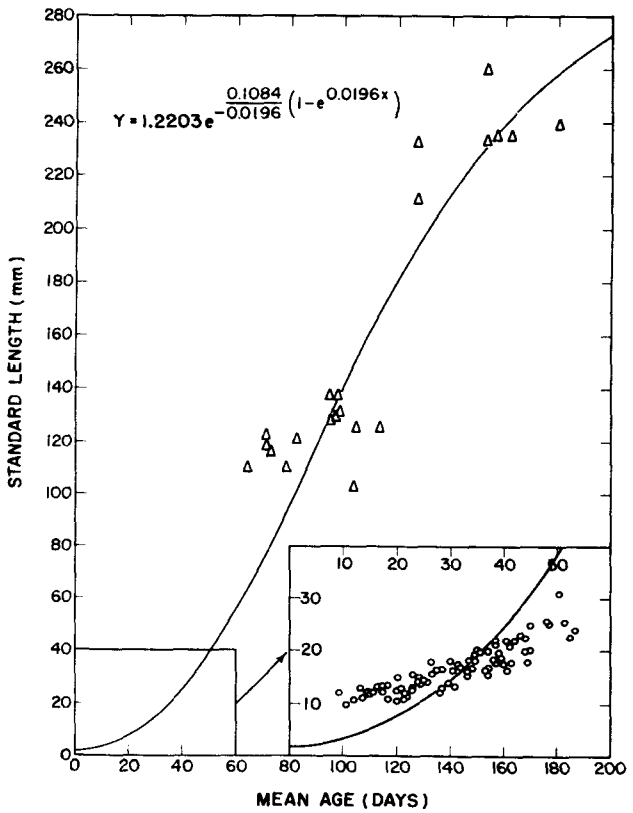

FIGURE 3.—Estimated age at length for all *Anoplopoma fimbria* in the study. Specimens taken in neuston nets (n = 84, including the 13 from 1983) are represented by circles, 1981 juvenile specimens from purse seine collections (n = 21) are represented by triangles. The equation and line represent the least squares fit of the Laird-Gompertz growth model.

where L_t = standard length (mm) at age t (d), L_0 = initial length (y-intercept), and A_0 and α are fitted parameters (Table 2).

This sigmoid curve suggests relatively slow growth to an age of about 50 d and a length of about 25 mm SL, followed by rapidly accelerating growth through the juvenile stage, an inflection point at 113.2 mm, and an asymptotic length near 307.8 mm. Since sablefish achieve lengths to 100 cm (Hart 1973), these results should not be extrapolated beyond the ages in the present study. Also, the predicted fit of zero age individuals (L_0) is 1.22 mm SL (Table 2; Fig. 3). This value does not accurately reflect the length of sablefish at hatching. Egg size in sablefish ranges from 1.8 to 2.2 mm and newly hatched larvae are 5 to 6 mm (Mason et al. 1983). If daily increments are first laid down at first feeding as in some other species (Laroche et al. 1982), then this intercept is clearly an underestimate. Mean egg size suggests a length at first feeding of about 8 mm (Shirota 1970). The smallest larva taken in the present study was 9.8 mm SL (Fig. 3). This part of the curve may be related to the inclusion of the older, slower growing neustonic specimens. Another factor may be effects of shrinkage; small specimens were preserved in ethanol, older juveniles frozen. The magnitude of shrinkage for *A. fimbria* is unknown, but capture and preservation of other fish larvae causes shrinkage which decreases with increasing age or size (Theilacker 1980). Thus increases in actual length for small individuals may have been relatively greater, changing the fitted equation and possibly increasing the length at time zero (Fig. 3).

Heyamoto (1962) estimated growth for young sablefish, suggesting that specimens 12.3 to 16.4 cm FL (11.1 to 14.8 cm SL) were 6 mo old. His data, however, were based upon estimating the age at collection by difference between capture and an assumed spawning season. In our study, 6-mo-old specimens were > 24 cm SL. The specimens captured by Heyamoto (1962) were taken by trawl in 320 to 412 m, much deeper than the epipelagic juveniles in our study. Beamish et al. (1983) used daily increments as part of a study to validate annulus formation in sablefish. In nine specimens 23 to 27 cm FL (208 to 245 mm SL), they observed from 270 to 350 (mean 313) increments but suggested that the fish were 1 yr old due to the inability to count all increments. Based upon our growth curve (Fig. 3), their ages would be overestimates.

Recent observations of laboratory growth are in substantial agreement with growth described by our curve. Shenker and Olla[3] found average growth rates as high as 2.3 mm/d for juvenile sablefish fed ad libitum. These fish were near the lengths where our curve predicts fastest growth (2 mm/d, Fig. 3). High growth rates were also observed for fish smaller than 25 mm, where our data suggest relatively slow growth. Grover and Olla[4] noted starvation of field-collected sablefish larvae based upon morphological criteria; thus food probably limits sablefish growth in the field. This species apparently has a great scope for growth given high laboratory rations or patches of high prey density in the field.

TABLE 2.—Fitted parameters of the Laird-Gompertz growth model for larval and juvenile *Anoplopoma fimbria* in the present study. The curve is fitted to all larvae and juveniles (N = 105) based upon counts of otolith increments.

Parameter	Estimate	Asymptotic standard error
L_0	1.2203	0.4675
A_0	0.1084	0.0146
α	0.0196	0.0015

The distribution of dates of first increment formation were estimated by back calculating from the ages of all specimens in our study. Since larvae and juveniles were from different years and sampling gears, it is possible that differences would be observed in this distribution. Since the plankton gear selects for smaller larvae due to avoidance by later stages, the results could be biased if the entire spawning season were not sampled. The median dates for the 1982 larvae (8 April) and the 1981 juveniles (18 March), however, were similar. Thus all 105 samples were combined and the distribution of the dates of first increment formation plotted (Fig. 4). The distribution has a mode in early April. If the first increment is formed in association with first feeding, as in most other species studied (Brothers et al. 1976; Taubert and Coble 1977; Laroche et al. 1982), then the spawning dates would precede the distribution in Figure 4. Ware (1975) provided an egg size-incubation time relationship for fishes; sablefish, with a 2 mm egg, would have an incubation time of 13 d. If a similar time is spent in yolk absorption before first feeding, peak spawning would occur in early March. This generally agrees with most other reports of the spawning season for *A. fimbria*.

[3]Shenker, J., and B. L. Olla. Laboratory growth and feeding of juvenile sablefish, *Anoplopoma fimbris*. Unpubl. manuscr.

[4]Grover, J., and B. L. Olla. Field evidence for starvation of larval sablefish, *Anoplopoma fimbria*. Manuscr. in prep. Northwest and Alaska Fisheries Center, Newport Field Office, National Marine Fisheries Service, NOAA, c/o Marine Science Center, Marine Science Drive, Newport, OR 97365 (direct correspondence to B. L. Olla).

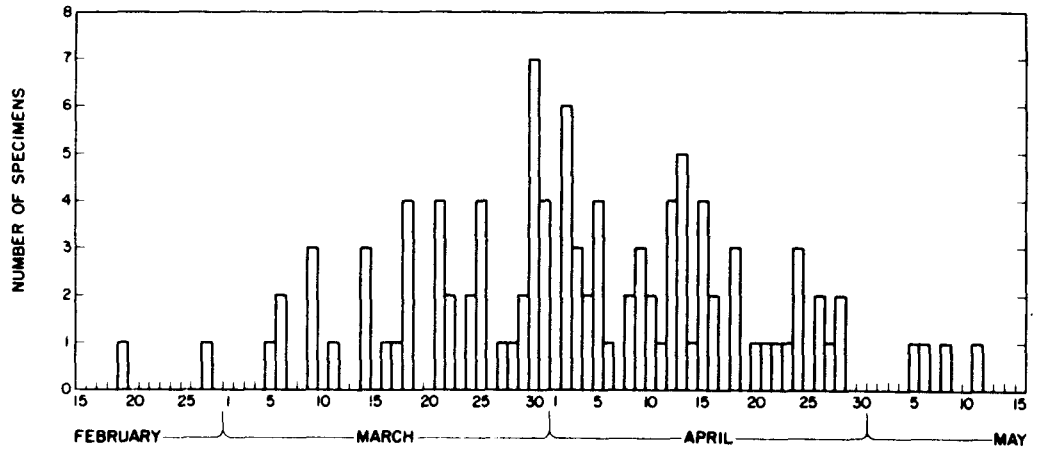

FIGURE 4.—Distribution of dates of first increment formation for *Anoplopoma fimbria*, determined by back-calculations using age and collection date.

Phillips (1958) defined the peak spawning season off California to be January-February. Bell and Gharrett (1945) suggested that the spawning season was around December off Washington based upon fishermen's observations and the presence of spent females in January. Farther north, Thompson (1941) observed ripe females and fertilized eggs in March at Cape St. James (lat. 51°45'N). More recent work has shown that the spawning season off British Columbia occurs in January to February with the peak of spawning in February (Mason et al. 1983).

Our observed growth rates for *A. fimbria* during the first 6 months of life are high for a temperate-subarctic species, yet are clearly below the potential growth rate as shown in the laboratory (Shenker and Olla footnote 3). Similar but lower laboratory growth rates (1.2 mm/d) were observed for 100 to 150 mm juvenile red hake, *Urophycis chuss*, by Luczkovich and Olla (1983). Both of these species contrast markedly with larval juvenile growth in other taxa. Boehlert and Yoklavich (1983), for example, summarized laboratory and field growth measurements for 13 species in the genus *Sebastes* and noted growth rates ranging from 0.092 to 0.590 mm/d. Young sablefish thus utilize the neustonic and pelagic environment to rapidly reach sizes at which migration to the benthic adult habitat occurs.

Acknowledgments

This work was supported by the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, WA, through contracts 81-ABC-00192-PR6 and 83-ABC-00045. We thank A. W. Kendall, Jr., W. G. Pearcy, and J. Shenker for providing specimens for this study, Chris Wilson for technical assistance with otolith preparation, and R. Methot for reviewing the manuscript.

Literature Cited

BARKLEY, R. A.
1972. Selectivity of towed-net samplers. Fish. Bull., U.S. 70: 799-820.

BEAMISH, R. J., AND D. E. CHILTON.
1982. Preliminary evaluation of a method to determine the age of sablefish (*Anoplopoma fimbria*). Can. J. Fish. Aquat. Sci. 39:277-287.

BEAMISH, R. J., G. A. MCFARLANE, AND D. E. CHILTON.
1983. Use of oxytetracycline and other methods to validate a method of age determination for sablefish. *In* B. R. Meteff (editor), Proceedings of the International Sablefish Symposium, p. 95-116. Alaska Sea Grant College Program, Univ. Alaska, Fairbanks, Sea Grant Rep. 83-8.

BELL, F. H., AND J. T. GHARRETT.
1945. The Pacific coast blackcod, *Anoplopoma fimbria*. Copeia 1945:94-103.

BOEHLERT, G. W.
1982. Ontogenetic changes in growth and their relationship with temperature and habitat change. *In* G. M. Cailliet and C. A. Simenstad (editors), GUTSHOP '81. Fish food habits studies, p. 115-123. Proceedings of the Third Pacific Workshop, December 6-9, 1981, Pacific Grove, Calif.; Wash. Sea Grant Prog., Univ. Wash., Seattle, WSW-WO 82-2.

BOEHLERT, G. W., AND M. M. YOKLAVICH.
1983. Effects of temperature, ration, and fish size on growth of juvenile black rockfish, *Sebastes melanops*. Environ. Biol. Fishes 8:17-28.

BROTHERS, E. B., C. P. MATHEWS, AND R. LASKER.
1976. Daily growth increments in otoliths from larval and adult fishes. Fish. Bull., U.S. 74:1-8.

GEFFEN, A. J.
1982. Otolith ring deposition in relation to growth in herring (*Clupea harengus*) and turbot (*Scopthalmus maximus*) larvae.

Mar. Biol. (Berl.) 71:317-326.
HART, J. L.
1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180, 740 p.
HEYAMOTO, H.
1962. Age of young sablefish, *Anoplopoma fimbria* (Pallas) 1811. J. Fish. Res. Board Can. 19:1175-1177.
LAROCHE, J. L., S. L. RICHARDSON, AND A. A. ROSENBERG.
1982. Age and growth of a pleuronectid, *Parophrys vetulus*, during the pelagic larval period in Oregon coastal waters. Fish. Bull., U.S. 80:93-104.
LUCZKOVICH, J. J., AND B. L. OLLA.
1983. Feeding behavior, prey consumption, and growth of juvenile red hake. Trans. Am. Fish. Soc. 112:629-637.
MASON, J. C., R. J. BEAMISH, AND G. A. MCFARLANE.
1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (*Anoplopoma fimbria*) off the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 40:2126-2134.
PHILLIPS, J. B.
1958. The fishery for sablefish, *Anoplopoma fimbria*. Calif. Fish Game 44:79-84.
PRUTER, A. T.
1954. Age and growth of the Oregon sablefish, *Anoplopoma fimbria*. Pac. Mar. Fish. Comm. Bull. 3:121-128.
SAMEOTO, D. D., AND L. O. JAROSZYNSKI.
1969. Otter surface sampler: a new neuston net. J. Fish. Res. Board Can. 26:2240-2244.
SHIROTA, A.
1970. Studies on the mouth size of fish larvae. Bull. Jpn. Soc. Sci. Fish. 36:353-368.
SAS INSTITUTE, INC.
1982. SAS users guide. SAS Institute, Inc., Raleigh, NC, 494 p.
TAUBERT, B. D., AND D. W. COBLE.
1977. Daily rings in otoliths of three species of *Lepomis* and *Tilapia mossambica*. J. Fish. Res. Board Can. 34:332-340.
THEILACKER, G. H.
1980. Changes in body measurement of larval northern anchovy, *Engraulis mordax*, and other fishes due to handling and preservation. Fish. Bull., U.S. 78:685-692.
THOMPSON, W. F., JR.
1941. A note on the spawning of the blackcod (*Anoplopoma fimbria*). Copeia 1941:270.
WARE, D. M.
1975. Relation between egg size, growth, and natural mortality of larval fish. J. Fish. Res. Board Can. 32:2503-2512.

GEORGE W. BOEHLERT

College of Oceanography and Marine Science Center
Oregon State University
Newport, OR 97365
Present address:
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
P.O. Box 3830
Honolulu, HI 96812

MARY M. YOKLAVICH

College of Oceanography and Marine Science Center
Oregon State University
Newport, OR 97365